STEEL AND PIPE MILL TECHOLOGY

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Summary

This chapter reviews the range of pipe making technology concepts that engineers need to know before specifying pipe for purchasing. Vigilance is required to ensure that the entire pipe order meets the performance requirements as specified in the purchase order. Quality control procedures are essential throughout the whole manufacturing process, not just the pipe mill. For example the pipe purchaser and the pipe mill need to ensure the raw steel ingots and slabs are suitable. Each rolling mill uses a unique deformation and accelerated cooling practice to roll the steel plate, the pipe mill forms and welds the pipe and then tests to ensure the required geometry, strength and toughness requirements are met.

1. Background

Steel pipe has a long history of use in gas transmission pipelines. It replaced the original wooden pipes which were originally used for low pressure localized service. Cast iron and wrought iron pipe were first used for town gas before World War One. Town gas was made by heating coal to incandescence and then quenching it in water. The resulting wet carbon monoxide was distributed to the area around the plant through cast iron and wrought iron pipe usually laid under the street. The gas was generally used first used for lighting, then cooking, but not for heating. Town gas was replaced by electricity for lighting, and electricity, natural gas or oil for cooking. Most big cities had town gas plants in the early 20th century but by the Second World War most had become uneconomic and they disappeared. However some of these original town gas mains are still in low pressure natural gas service some for more than a century.

The first natural gas pipelines were built to carry gas from a well to the local town. The earliest 2 inch (50mm) line was in Pennsylvania but the lack of leak proof couplings limited this use to relatively short distances. After World War One advances in metallurgy and welding lead to the construction of the first pipelines and by the end of the 1930's almost a dozen pipeline companies were in business in the United States of America. The Natural Gas Pipeline of America was one of the longer delivering natural gas from Texas to Chicago while Texas Eastern went from Texas to New York.

Today's statistics show that there are over 300,000 miles (480,000 km) of transmission and almost 1.6 million miles (2.5 million kilometers) of distribution pipe pipeline mains in the USA. Of the transmission lines about 5% were built before 1940, and about 2/3 built before 1970. The early 1970's saw the peak movement of gas almost 3 trillion cubic meters a value that has yet to be exceeded in 2009. After the energy crunch of the early 1970's this volume had decreased by almost half at the end of the 1980's and has been slowly growing to be about 2.5 trillion by 2006. Much of the infrastructure growth since the 1970's has been to add flexibility and service additional cities. Only recently has there been a new truly long distance transcontinental pipeline built, Alliance from Alberta to Chicago. Smaller lines i.e. offshore Nova Scotia to Boston, have been put into service and one day Alaska will hook into the "pre-build" system which now links the Peace River district of northern Alberta into the mid-West.

Distribution pipeline transmission mains are generally smaller, 4 inch (100mm) to 12.75 inch (300mm) diameter, and usually operate at lower pressures below 40 atmospheres around the perimeter and into the core of a city. There are almost 1.25 million miles of plastic pipelines in low pressure service in North America. Transmission pipelines generally run through multiple states, range in diameter from 24 inch (400mm) to 48 inch (1200mm) and operate at pressures from 30 to almost 100 atmospheres. This white paper will focus on these transcontinental pipelines. The bibliography provides additional helpful insights into the historical, economic and technical reasons driving the acceptance of high grade steels.

2. Historic Pipe Making Practices

Today the steel used to make pipe is "fully killed" or deoxidized as explained later. The steel plate that is to be formed into pipe is commonly called "scalp". For a common internal pressure, the wall thickness increases with both diameter and by Design Factor commonly known as "location class": one being rural areas, two – road crossings, three – compressor stations and suburban areas, and finally four - high density with four story or more apartment buildings. Increasing the pipe yield or grade allows a proportionately lighter wall thickness and helps reduce the cost of the steel and welding but requires increased pipe mill technology, quality controls, and especially when historical limits on horsepower demand new procedural controls. Helpful images (worth thousands of words) to support this contribution can be found in older, and unfortunately out of print volumes. The best collection of detailed drawings and images can be found in the USS Steel Handbook (the latest 10th Edition of 1985, has edited out many of the earlier technologies), and Electric Furnace Steelmaking 1985. For those who desire a more detailed discussion of pipeline considerations after completing this encyclopedia segment a good place to start is Stalhein's recent paper on "Alloy Designs for High Strength Oil and Gas Transmission Line Pipe Steels".

3. Rolling Mill Configurations

3.1. "U & O" Process:

Most large diameter pipe was made by one of a number of "U&O" processes. Steel plate is first slit to the correct width, the circumference of the finished pipe and the edges milled to ensure the blank is square and of the correct dimension. In more modern mills the plate is ultrasonically scanned as the width of the plate passes under multiple, evenly spaced, UT inspection heads to ensure there is no lamination. In the standard U&O process, the first pass is through a crimping machine. Here the plate edges are first bent or rolled into the correct curvature to prevent a flat surface at the long seam weld. The second stage uses a large U shaped die to press the plate into a series of rocker type dies that lie along the axis of the plate. A large U die is pressed down and the plate is formed into the U. The pipe then goes to the "O"ing machine where an upper half-round die presses the U into a matching lower half-round die, to form an almost closed cylindrical shape ready for welding. The width of the plate mill sets the maximum circumference and hence the finished pipe diameter. The long seam weld is usually a submerged arc weld (SAW) on ID followed by the OD as a dual SAW (DSAW). If a high frequency electric resistance weld then the process is known as "UOE". Some pre 1970 UOE pipes were low frequency welded and had much higher electrical contact resistances (see 4.2)

3.2. Roll Forming

A few mills use three rolls set in a triangular "pyramid" pattern http://www.bergpipe.com/. The two lower rolls are parallel and set apart at a fixed spacing. The 40 foot long steel plate is continuously passed back and forth between the single upper roll and the two lower rolls. The upper roll can also be bent to ensure uniform forming. In each pass the upper roll is driven further into the space between the lower rolls forcing the plate to U and then eventually into an O. Some claim these roll forming mills can quickly adjust to roll a wider range of diameters and wall thicknesses than more common pipe making mills.

The seam weld edges are crimp rolled to the proper profile with a convex hydraulic internal roll pressing against a matching hourglass external roll. The formed cylinder is extracted and placed into the welding machine were the long seam is automatic gas metal arc tack welded (GMAW) as the cylinder is squeezed to give the correct root spacing. Run on and off tabs are welded to the ends of the seam weld and the internal then external submerged arc welds (SAW) are deposited. The internal SAW melts the GMAW and the external SAW melts the root of the internal SAW. The DSAW weld is dressed by grinding if needed to maintain the correct weld profile height. Some mills like Berg Steel in Pensacola FL use Xray fluoroscopy to inspect the entire weld in real time, once completed, but the only ends of every DSAW joint needs to be X-rayed. The pipe is roll formed to ensure continuous roundness over the full length. The ends are then faced parallel and smoothed to both provide a seal in the next step of hydrostatic testing and as a preparation for weld profile machining in the field. The pipe is then pressure-sealed against elastomeric ring, filled with water and pressurized as required to assure the strength for that grade is met and that there are no defects that will grow to leak. Many steel mills then use ultrasonic inspection to ensure there no cracks or other defects that have been forced open in the weld cross section and if required, in the pipe body. For the same reason the last 150mm of both ends of the DSAW joints are X-rayed. The pipe is then weighed and inspected to ensure it falls inside the API 5L geometry limits. The pipe once it passes all the requirements is labeled. Some operators ask to have the mill SAW to join two 40 foot long pipes into a “double joiner” which cuts the number of field welds by half. If required, the mill can also coat the pipe exterior with a corrosion resistant coating and the interior with a coating to reduce the gas friction. The pipe is then loaded and shipped to storage or directly to the construction site.

Each step requires qualified personnel and also must meet a number of international standards. An alphabet of international standards are called up in the most contracts but are usually based on the common international pipe standard American Petroleum Institute (API) API 5L “Specification for Linepipe” which includes quality control considerations, API 1104 “Welding of Pipelines and Related Facilities”, National Association of Corrosion Engineers (NACE-International) NACE “RP0394 Application Performance and Quality Control for Plant-Applied Fusion Bond Epoxy External Pipe Coatings” for the surface preparation and CSA Z245.20-06/Z245.21-06 External fusion bond epoxy coating for steel pipe/External polyethylene coating for pipe. , American Society for Nondestructive Testing (ASNT) for the various visual, ultrasonic and X-Ray inspection technologies and inspector qualifications, and various international and country standards for quality control. Standards provide value by establishing common expectations, and suggesting minimum requirements. Company procedures interpret these requirements to establish every day purchase and operating practices. Operators who purchase the pipe usually have the steel mill meet additional requirements, strict process controls and consistent standard operating procedures which exceed the requirements outlined in the international standards. Many of these additional requirements are driven by experience while only the initial QA/QC needs are outlined in the API 5L pipe standard. Experiences are translated into the purchase contract between the mill and the operator.

A straight long seam is the outcome from U & O or another linear process, providing the width of the steel plate is ≥ PI times the diameter. Sometimes the plate mill cannot roll plate wide enough to make the large diameter pipes, in this case the plate is fed at an angle and is wrapped into the round pipe shape as a spiral or helical form.

3.3. Spiral Pipe Process

Larger diameter “long seam” pipe is generally limited by the width of the plate a mill can roll. A maximum width of 3.0 m (100 in circumference) restricts the diameter to < 36”. Pipes with a larger diameter are generally made in spiral mills. . The width of the plate no longer limits the pipe diameter. The scalp coil is unwound then is checked for lamination, trimmed and squared as before, and the weld preparation is completed on both edges. The plate ends are fusion welded one to the other to make a endless strip feed into the spiral mill. The prepared steel is fed into the mill at an angle that is the function of the final diameter. The plate is formed into a continuous spiral tube and the root is tacked in place, most likely using automatic gas metal arc welding (GMAW or MIG). This tack weld helps both to hold the round shape and ensure weld geometry remains constant while the full spiral weld is deposited. First the inside of the spiral weld seam is submerged arc welded (SAW) at the bottom or 6 o'clock. This pass melts and removes the MIG weld tack. The second SAW weld is generally made when the pipe has rotated to the top or 12 o'clock position. The OD SAW pass remelts the pipe center part or root of the ID SAW to provide good alloy homogeneity. Both welds complete the joint. . In many cases one or more welding consumable wires are used to increase the production speed. This pipe is said to be dual submerged arc weld (DSAW). Both the fused and granular welding flux is collected, ground and recycled. Care must be taken to ensure welding flux doesn't become too diluted with welding slag and the lean composition lead to porosity and other weld defects.

Most pipe is made into pipe diameters smaller than 500mm or 20". A wide steel plate can be made into several smaller diameter pipe by slitting the plate to the proper width. These new edges need to be inspected for lamination especially if the plate was not previously inspected. Refractory, slag, and other impurities trapped in the solidifying liquid steel plus some solidification impurity concentrations generally cause these laminations in the steel plate. These abnormally high chemistry differences generally cause weld solidification problems when completing the long seam.

Plate properties are anisotropic, different in all three coordinates, the transverse strength and toughness is generally just less than the longitudinal, and the through thickness toughness can be much less for not so clean steels. The angle of the weld to the axis means that the plate properties are a cosine vector with the axes the properties found in the plate rolling and transverse directions. The actual tensile properties however are usually close to the average of the two directions.

3.4. Continuous U&O Mills

The pipe goes through a multiple series of rolling stands. As the plate passes through each roll stand it gets formed into a dish then a U and then forms the ends of the U into an O as the plate rolls successively through the stands. The spacing to set the weld root gap in the opening is controlled in the last passes depending on the welding process which will be used. The best photos are found in USS Making Shaping and Treating of Steel. A range of different and innovative welding processes have been used, some like laser with multiple wire feeds have shown considerable success.

3.5. Seamless

Rather than starting with plate, the seamless pipe mill requires a solid reheated billet. The end of the billet is pierced and a set of off axis rolls, both forge and roll the white hot billet into a tube. The end of the piercing tool is the interior rolling surface and the ID expands as the as the billet is rolled and squeezed thinning and growing in diameter as it progresses down the piercing head. The ID increases to the final diameter as the round white hot billet progresses down the shaft until the entire billet is rolled into pipe. The wall thickness for seamless pipe is harder to control than when rolling plate, for photos see Making Shaping and Treating of Steel. . This slightly higher variation in wall thickness is offset by the elimination of the long seam.

4. Historic Seam Welding Processes

Operators may still encounter some archaic technologies and these lap weld, hammer seam, furnace butt, lap butt, continuous butt, single submerged arc welding, flash welded, low-frequency electric resistance welding, are all pictured in Making Shaping and Treating of Steel, Integrity Characteristics of Vintage Pipelines, and History of line Pipe Manufacturing in North America.

Readers might uncover some of the more archaic seam weld technologies in excavating older pipe. Early pipe was also made from plate formed into a tube. Earlier pipe makers often used various forge welding techniques, to close the seam of the rolled up plate, and make pipe. The simplest method was the lap weld. The plate was generally bevel cut or scarfed (like a wood joint) on an angle to maintain the same wall thickness, but sometimes one surface was simply overlaid, one on top of the other. The lap weld began by heating the overlapping bond region; sometimes the whole pipe body was heated in a furnace. The overlapping edges were squeezed together between a roll on the exterior and a ball on the interior. The pressure exerted in the through - thickness direction accomplished two tasks; first it extruded the surface oxides as flash and then it allowed the now clean heated surfaces to diffusion bond as a true weld. Hammer seam pipe was made by feeding the preformed overlap under a trip hammer. Generally these lap seam welded pipe if scarfed went through follow up series of rolls to ensure the final diameter and remove any ovality.

4.1. Furnace Butt Joints

Furnace butt joints were made in a similar fashion. The whole pipe was heated and then run through a set of rolls that squeezed, forged and welded together the two edges of the plate to make a closed tube. The forging also squeezed the oxides out into an extruded lip and allowed the clean steel surfaces to diffusion weld. The flash lips were then trimmed leaving a flat profile slightly higher than the ID and OD of the pipe.

4.2. Low Frequency Electric Resistance Welding (LF-ERW)

Sometimes mills used DC rather than low frequency AC (50 & 60 hz) current to heat the joint surfaces to a sufficiently high enough temperature to allow forging as butt welding. Rather than heat the entire pipe joint, two electrical brushes or shoes contacted the pipe just prior to the “o” shape entering the final pass in the pipe mill. The electrical current heated the surface to be welded. The mill squeezed the heated face to extrude the surface oxides from the butt weld and forge weld the two edges together making the long seam. The path of the heating current entering the pipe through one electrical shoe, traveled down the weld surface to where the gap in the “v” ended, i.e between the two rolls, and then back up the other side to the other contact shoe. Low frequency and DC currents were notoriously sensitive to the contact resistance of these shoes on the pipe surface. Most mills did a good job. Those with the poorest surface cleaning and thick mill scale had delivered some pipe that had incomplete fusion or even intermittent or “stitched” welds. The extrusion of the welded surface in these butt - fused welds bent the rolling microstructure to almost right angles as it squeezed out from the plastic weld volume. If the plate had interior lamination then this in-homogeneity would be bent to the surface. In some cases the steel after deformation would open down this weak layer giving rise to a defect known as “hook cracks”. These older technologies were basically phased out before 1970s.

5. Current Seam Welding Processes for Straight And Spiral Welded Pipe.

5.1. High Frequency Electric Resistance

(HF-ERW) overcame the earlier contact resistance problems, because it is much more insensitive to surface oxidation. The resulting magnetic field caused by the HF current also helps by using the “skin effect” confining the current in the “v” gap which reduces the volume of metal heated restricting the energy to just that surface to be welded.

5.2. Dual Submerged Arc Welded

(DSAW) technique uses an internal followed by an external SAW pass to complete the seam weld. Run out tabs are tacked to the ends of the pipe to ensure that the weld puddle finishes and solidifies away from the pipe. Usually the seam is first oriented to the 6 o’clock or down position and squeezed together to produce the right gap while making a SAW pass on the ID. The seam is then rotated to 12 o’clock and the OD SAW welded with the root of the ID pass re-melted as part of this second weld. The joint is then inspected for defects in least the last foot of each end but now in many cases the mill will X-ray the entire weld in real time.

5.3. Laser and Electron Beam

Welding techniques have been used to minimize the amount of filler materials and the size of the heat affected zone. Electron beam works best in a partial vacuum and the vacuum minimizes the beam scatter. Both need a square face preparation and some filler wire to ensure the cap height remains positive. Both are still considered experimental for use in the mill but have been tried in the field with very attractive economics in the construction of offshore pipelines.

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Bibliography

ASM Metals Handbook Volume 1 Properties and Selection: Iron and Steels 9th edition 1978 Available from ASME International Library Service, 889 N. Freedom Blvd. #100, Provo, Utah, USA, 84604 [This volume contains summaries for the properties of all the steel alloys most engineers will need for design purposes. Currently ASME sells a 1990 update.]

C. R. Taylor (ed) (1985) Electric Furnace Steelmaking, Iron and Steel Society Inc, printed by BookCrafters Inc, Chelsea MI. [Another excellent source of images and technology descriptions, earlier editions had many more descriptions of vintage equipment which was edited out of the recent version].

D. G. Stalheim, K. R. Barnes, D.B. McCutcheon, (2007) ALLOY DESIGNS FOR HIGH STRENGTH OIL AND GAS TRANSMISSION LINEPIPE STEELS International Symposium on Microalloyed Steels for the Oil and Gas Industry Edited by W.J. Fazackerley, P. Bordignon, K. Hulka, and F. Siciliano TMS (The Minerals, Metals & Materials Society). [This describes different modern approaches to the making of pipe specifically for the Arctic use such as the Alaska gas pipeline].

E Clark & B Leis, (2002) Integrity Characteristics of Vintage Pipelines, INGAA Foundation, F-2002-50435 10 G St NE Suite 700, Washington DC [Describes pipe making technologies and related incident histories, a very good summary with helpful illustrations].

JF Kiefner and EB Clark, (1996) History of Line Pipe Manufacturing in North America ASME Research Report CRTD-Vol.43 ASME 345 E 47th Street New York NY 10017, 1996 p292 pages Book Number IO0396 [Lists all the pipe mills that held API certification from 1911 to 1995. It also has photos of vintage pipe making processes].

Metals Handbook 8th Edition Metallography, Structures, and Phase Diagrams, copyright ASM 1973. Available from ASME International Library Service, 889 N. Freedom Blvd. #100, Provo, Utah, USA, 84604 [This volume is a treasure house of steel related phase diagrams. It is essential to help your understanding of the reason why certain alloys are chosen and to predict their performance on cooling. Currently ASME sells two volumes Vol 3 Phase Diagrams 1992 and Vol 9 Metallography 2004]

R Grill, R Schimboeck, D Petermichi, D van der Hout, (2003) Plates for Pipes, World Pipelines, July/August 2003, pages 62- 66. [This paper describes the alloying, solidification, and thermo-mechanical rolling and accelerated cooling schedules to produce grades from X65 to X100 steels on a new mill. Good presentation to show the effects of quality control means and standard deviations for upwards of 600 heats].

Siciliano F, Stalheim D G, Gray M, et al (2008) IPC2008-64292 – "Modern High Strength Steels for Oil and Gas Transmission Pipelines" –Proceedings of the IPC2008 7th International Pipeline Conference September 29 to October 2008 Calgary Alberta Canada. [This paper suggests a process for making high grade steels in older mills that may not have the horse power or cooling rates needed].

The Making Shaping and Treating of Steel, 10th Edition, United States Steel, AISE 1985, [Provides an excellent source of images and technology descriptions, earlier editions had many more descriptions of vintage equipment which was edited out of the 10th and most recent version].

Suggested Reading for Additional Details

Pipe Making

Bremer S, Flaxa V, & Knoop FM,, IPC2008-64678 –"A Novel Alloying Concept for Thermo-mechanical Hot-Rolled Strip for Large Diameter HTS (helical two step) Line Pipe" –Proceedings of the IPC2008 7th International Pipeline Conference September 29 to October 2008 Calgary Alberta Canada. [It offers an alternate high Niobium alloying process to make high strength thicker wall steel pipe.]

Gray M, et al, IPC2008-64292 – "Modern High Strength Steels for Oil and Gas Transmission Pipelines" –Proceedings of the IPC2008 7th International Pipeline Conference September 29 to October 2008 Calgary Alberta Canada. [This suggests a process to make high grade steels in older mills. It has a good description of the ideas behind microalloy techniques to achieve high strength.].

HG Hillenbrand, F Grimpe, A Liessen & V Schwinn Manufacturing of X100 Pipes for the TAP Project, IPC2006-10257, 6th International Pipeline Conference Sept, 2006, Calgary, Alberta Canada, ASME [This describes the making of U&O X100 pipe with properties and fatigue testing. [Shows the beneficial effect of the fusion bond epoxy curing heat cycle on strength and toughness].

R Grill, R Schimboeck, D Petermichi, D van der Hout, Plates for Pipes, World Pipelines, July/August 2003, pages 62- 66. [This paper describes the alloying, solidification, and thermo-mechanical rolling and accelerated cooling schedules to produce grades from X65 to X100 steels on a new mill. Good presentation of quality control mean and standard deviations for upwards of 600 heats].

Hydrotesting

A.R. Duffy, G.M. McClure, W.A. Maxey and T.J. Atterbury. “Study of Basing Natural Gas Pipeline Operating Pressure on Hydrostatic Test Pressure”, NG-18, Research, PRCI Catalog L30050, Pipeline Research Council International, Arlington, Virginia, USA 1969. [Describes the expansion of pipe due to hydrotesting to 110% SMYS and above.]

Effect of Yield to Tensile Ratio

Denys R & Lefevre A A “Material Test Requirements for Strain Based Pipeline Design”, International Symposium on Microalloyed Steels for the Oil & Gas Industry edited by W. J. Fazackerley et al, TMS 2007. [Discussion of the Y/T ratio and it’s effect on residual ductility for high strength steels.}

F Hamad et al, IPC2008-64099 – X100 (Grade 690) Helical Welded Linepipe, Proceedings of the ASME IPC2008 International Pipeline Conference, Sept 25-Oct 3/08, Calgary, Alberta, Canada. [This is a good discussion of the alloying concept, thermo-mechanical controlled processing, and the resultant microstructures and mechanical properties along with the key processing parameters which control the microstructure and mechanical behavior to produce an X100 steel.]

F Hamad et al, IPC2008-64101 – Determination of Mechanical Properties of High Strength Line Pipe, Proceedings of the ASME IPC2008 International Pipeline Conference, Sept 25-Oct 3/08, Calgary, Alberta, Canada. [consideration of the Bauschinger effect in testing of pipe after pipe making.]

G Knauf et al, IPC2008-64553 – Investigation of the Stress-Strain Behaviour of Large Diameter X100 Linepipe in View of Strain-Based Design Requirements, Proceedings of the ASME IPC2008 International Pipeline Conference, Sept 25-Oct 3/08, Calgary, Alberta, Canada. [Good discussion of the effect of FBE thermal cycle on final mechanical properties.]

Hohl G, Knauf G, & Vogt G, “Field Testing and It’s Significance to Modern Pipelines” ERPG-PRCI 12th Biennial Meeting on Pipeline Research, Groningen, The Netherlands, May 17-21, 1999, pp 32-1 to 32-16. available from www.PRCI.org

J. Zhou et al, IPC2008-64427 - Strain Aging Effects in High Strength Line Pipe Materials, Proceedings of the ASME IPC2008 International Pipeline Conference, Sept 25-Oct 3/08, Calgary, Alberta, Canada. [A good description of the expected changes in pipe properties due to the FBE thermal cycle after pipe making.]

Nessim M, et al, IPC2008-64478 – “Dealing with Knowledge Uncertainties in Pipeline Reliability Based Design and Assessment” –Proceedings of the IPC2008 7th International Pipeline Conference September 29 to October 2008 Calgary Alberta Canada, [Good discussion of sources of error and how to deal with them to best describe the statistical performance of pipe.]

Zhou J et al, IPC2008-64518 – “Strain Capacity of X100 High-strain Linepipe for Strain-based Design Application” –, Proceedings of the IPC2008 7th International Pipeline Conference September 29 to October 2008 Calgary Alberta Canada. [Good discussion of the use of FEA for frost heave designs based on the statistical description of pipe properties.]

Biographical Sketch

Dr Keith G Leewis P.Eng. has over thirty years of extensive and comprehensive practical experience in pipeline engineering, design, materials, operations, and integrity management, in the operations and engineering sectors of the natural gas industry, as an R&D engineer in DOFASCO’s integrated BOF steel plant, and on the open hearths at Sydney Steel, as Director of Technology at the Welding Institute of Canada, and as a tenured engineering professor, Technical University of Nova Scotia. Now as a consulting engineer, he provides technical assessments that assist clients in achieving timely regulatory approvals. As a member of numerous ASME and NACE committees, he improves the international standards for the design and integrity management of natural gas pipelines, including other standard development organizations related to integrity assessment.